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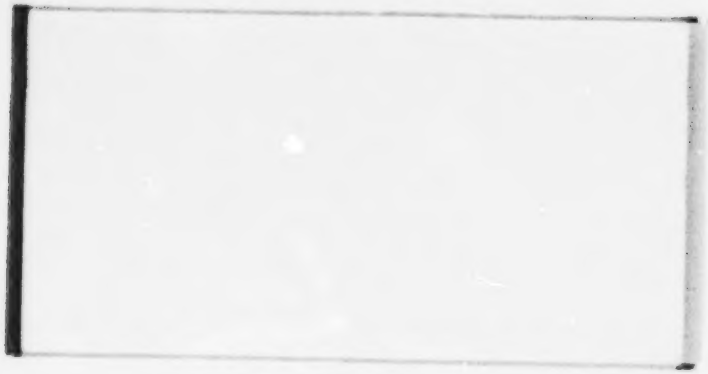

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TRACE ELEMENT DEPOSITION MODEL: PHASE III - SELECTION OF A MODELLING APPROACH

Report No 85-247-K

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ABSTRACT

This is the third report exploring the dispersion and deposition of trace inorganic elements and particles emitted from Ontario Hydro coal-fired power plants. This report reviews a selection of suitable Gaussian plume models and recommends a credible modelling approach for determining long-term average trace element deposition at Ontario Hydro power plant sites. The Battelle Pacific Northwest Laboratory's trace element deposition model 'CLIDE' was selected with recommended improvements to the plume rise and wet deposition algorithms. A detailed Phase IV trace element deposition model implementation and development program is outlined along with a time schedule and budget proposal.

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EXECUTIVE SUMMARY

TRACE ELEMENT DEPOSITION MODEL: PHASE III - SELECTION OF A MODELLING APPROACH

G.C. Edwards

A review of 20 Gaussian models was undertaken against model selection criteria proposed by Edwards (1984) as part of Phase III of the Trace Inorganic Element Deposition Study. A modelling approach for determining long-term average trace element deposition patterns at Ontario Hydro thermal power plant sites was formulated. It involved the use of the Battelle Pacific Northwest Laboratory's model 'CLIDE' with improvements recommended for the plume rise and wet deposition algorithms. The 'CLIDE' model was used for determining trace element deposition at Nanticoke as part of a CEA-funded trace element deposition program. It is envisioned that Phase IV of the research program will involve model implementation, data base establishment and model testing. A time schedule of 18 months and a program cost of $55,000 are proposed for Phase IV.

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To Mr. D.K.A. Gillies
Manager - Environmental Protection
Technical & Training Services

TRACE ELEMENT DEPOSITION MODEL: PHASE III - SELECTION OF A MODELLING APPROACH

1.0 INTRODUCTION

Fossil-fuelled power plants have operating life times of decades. It is therefore necessary to assess the potential for long-term environmental accumulation of the atmospheric pollutants emitted from these facilities. Countries such as Sweden, Germany, UK, Australia and Japan have undertaken studies of the impact of trace element emissions from fossil-fuelled generating facilities over the past few years, Coville (1985). A Canadian study of trace constituents has been carried out over the past 5 years by Battelle Pacific Northwest Laboratory under CEA sponsorship. Most all of these studies have taken a health effects approach. Modelling the atmospheric pathway of trace element emissions has received little attention. Trace element accumulations in the environment as a result of emissions from fossil-fuelled generating facilities do not appear to be sufficient to pose any health risks. However, it is important to be able to defend this position if faced with regulation. At present, there are no indications that the regulatory community has accepted trace constituent accumulations as a non-problem. Studies of trace element deposition are continuing in most countries. For example, EPRI in the US are spending 25 million dollars over the next 10 years on trace element deposition studies.

Recognizing that not enough was known about trace element deposition, Chemical Research Department spent >$1M studying emissions in the 1970's, well before CEA and Battelle became involved. More recently, the Environmental Protection Department (EPD) of Technical and Training Services Division (TTSD) contracted the Atmospheric Research Section (ARS) to undertake a multiphase study of the deposition - via the atmospheric pathway - of trace inorganic element and particulate emissions in the vicinity of Ontario Hydro's (OH) fossil-fuelled stations. Previous reports have dealt with characterizing trace inorganic element emissions, Kalvins (1983), and with identifying representative atmospheric models and model selection criteria, Edwards (1984). The purpose of this phase of the trace inorganic element deposition program was to assess the available models suited to modelling trace element deposition and, from this, propose a viable modelling approach.

This report presents the model review protocol in Section 2.0, the review of modules in Section 3.0, and the selection of a base model in Section 4.0. Discussion of the scope of the Phase IV work program is tabled in Section 5.0, along with the conclusions and recommendations.

2.0 MODEL REVIEW PROTOCOL

Edwards (1984) prescribed model selection criteria and a list of available models to be reviewed in this phase of the study. The model selection criteria were as follows:

- A Gaussian climatological model, suitable for the transport and dispersion of gaseous and particulate trace element emissions, containing state-of-the-art modules (as prescribed in this report) for plume rise, wind shear, reflection, dispersion coefficients, gravitational sedimentation, wet and dry deposition, and particle size distribution.

- The modelling region of interest should be within a radius of 25 km of the source.

- The model should be capable of computing seasonal or longer time averages.

- The model should be tunable for surface characteristics surrounding the Nanticoke, Lakeview, Lambton, Atikokan and Thunder Bay power plants.

- The model must be implementable on an Ontario Hydro computer.

- The model should use a practical amount of computer time, and the software should be user friendly.

The models selected for review are repeated in Table I.

The model Phoenix on the original list of models has been omitted here as a preliminary review revealed it to be a complex numerical model beyond the scope of the required application.

Documentation available for the models reviewed ranged from a computer code and a brief description to an 800-page user's guide. Further efforts to obtain information involved a library computer literature search using model acronyms and authors' names as search parameters and a brief literature search for Gaussian model review papers and reports. All information assembled, that is references, reports, papers, contacts etc, are available on request from the Atmospheric Research Section. In the process of information gathering, copies of the Fortran code for the models CLIDE and ISCST/ISCLT were obtained at no cost to Ontario Hydro.

TABLE I

Model	Organization
AQSTM	Illinois Environmental Protection Agency
ATM	Oak Ridge National Laboratory
CDM/CDMQC	US Environmental Protection Agency
CLIDE	Droppo, Allwind and Davis, 1982
CRSTER	US Environmental Protection Agency
GEM	Science Applications, Inc
ISCLT/ISC	H.E. Cramer Company, Inc
MESOPUFF	Environmental Research and Technology, Inc
MPTER	US Environmental Protection Agency
MSDM	Lawrence Livermore Laboratory
MULTIMAX	Shell Devlopment Company
PAL	US Environmental Protection Agency
PTDIS	US Environmental Protection Agency
PTAMX	US Environmental Protection Agency
PTMTP	US Environmental Protection Agency
RAM	US Environmental Protection Agency
SCIM	GEOMET, Inc
TCM	Texas Air Control Board
TEM	Texas Air Control Board
VALLEY	US Environmental Protection Agency

In order to assess long-term pollutant accumulations, a climatological deposition model, incorporating both wet and dry deposition processes on a long-term basis is required. Although Gaussian climatological models are widely used to assess long-term pollutant impacts, the credibility of such models is still being researched. Evidence of acceptable performance by Gaussian climatological models has been presented by Runca et al (1982), Droppo et al (1981), and Ragland et al (1980).

The models reviewed possessed one or more of the following general characteristics:

- Gaussian climatological model, long-term averaging time,
- applicable to the short-range, on the order of 25 km,
- computer programs and user's manuals are readily available,
- designed primarily for treating inert pollutant species,
- capable of treating deposition (ie, wet, dry),
- capable of reflecting complex topographical effects, and
- computer-practical, in terms of Ontario Hydro computer resources.

Not all of the 20 models selected were suitable in their entirety for Ontario Hydro application. The model review protocol adopted, involved the review of modules for the group of models which did not meet all selection criteria and a more complete review of models suitable in their entirety. The model review approach taken, then, was an optimization procedure in which the most suitable synthesis of model and model components was determined. The review protocol adopted allowed the selection of the most credible model.

A preliminary screening aimed at identifying those models whose components should be reviewed and those suitable for review in their entirety was the first step in the review process.

The screening criteria used were: appropriate averaging time, range of applicability, complex terrain capability and wet and dry deposition. All these attributes would be essential for a model to be considered in its entirety. Model averaging times are typically 1 h, 24 h or greater than 24 h (ie: seasonal, annual or longer-term averages). Table II presents the results of the preliminary screening.

TABLE II

	Averaging Time			Topography		Deposition	
	Episodic (<1 h)	Short-term (< 24 h)	Long-Term (>24 h)	Flat	Complex	Dry	Wet
TEM	x	x		x			
MSDM	x		x		x		
ISC		x			x	x	
ISCLT			x		x	x	
CLIDE			x		x	x	x
VALLEY		x			x		
MPTER		x			x	x	
ATM			x	x		x	
CRSTER			x		x		
MESOPUFF		x	x	x			
AQSTM		x			x		
CDMQC		x		x			
CDM			x	x			
PAL		x		x			
PTDIS		x		x			
PTMAX		x		x			
PTMTP		x		x			
RAM		x		x			
GEM		x			x		
SCIM		x	x		x		
MULTIMAX		x	x		x		
TCM			x	x			

Models considered suitable for evaluation as a base model were those that possessed the minimum attributes of: averaging times of >24 h, a basis for treating complex terrain, and dry deposition. A wet deposition module was not considered necessary at this stage because if a model possessed dry deposition algorithms then the addition of wet deposition is usually easily accomplished.

From Table II and the prescreening criteria, it is evident that the models most appropriate to form the basis of the OH trace element model are ISCLT and CLIDE. The remaining models are suited to review of their modules for possible inclusion in the base models.

3.0 REVIEW OF MODULES

Algorithms commonly encountered in Gaussian plume models that are considered important for Ontario Hydro application include parameterizations of the following physical processes:

- plume rise
- vertical wind shear
- vertical plume dispersion
- horizontal plume dispersion
- removal processes
  - wet deposition
  - dry deposition
- terrain interaction.

The purpose of this section is to review these modules in all the models in order to select state-of-the-science modules for inclusion in the base model if they are not already present. An overview of the six important modules follows.

3.1 Plume Rise

The most commonly used formulations for plume rise are those proposed by Briggs in 1969 and subsequently. Briggs' formulations are the most physically sound. Other formulations tend to be empirically based. A complete review of plume rise formulas and discussion can be found in Edwards (1983) and Briggs (1975). Edwards (1983) tested various plume rise formulations using measured plume rise data from Nanticoke. The results showed that the Briggs formulation was the best predictor. Also demonstrated was the fact that the empirical constant for entrainment used in Briggs formulation should be modified when the model is used in land/lake environments, Edwards (1984). The use of Briggs' more recent formulations is distinguished from the use of his earlier formulas, since Briggs revised his formulas for buoyant plume rise under stable, unstable and low-wind speed conditions slightly, since 1969. In terms of tabulating the formulas used in the models reviewed, the following plume rise categories were used:

(a) Briggs Pre-1969
(b) Briggs Post-1969
(c) Non-Briggs' Formulation

Obviously none of the models reviewed will contain the modified Briggs formulation by Edwards as this is a site specific formulation. However, this is the most appropriate plume rise model for Ontario Hydro's lakeshore sites. The more recent Briggs formulations are the preferred choice for the other Ontario Hydro sites, such as Atikokan TGS.

3.2 Vertical Wind Shear

Wind speed varies as a function of height. Vertical wind velocity shear is usually treated in one of the following methods:

A) Assuming that the wind speed is constant in the vertical and that the wind speed measured at a reference height is representative.

B) Extrapolating the wind speed from a reference level to the stack height or the effective plume height, based on:

   (i) stability-dependent power law formula,
   (ii) stability-corrected log law formula,
   (iii) Rossby number similarity theory.

C) Using a mass-consistent wind model to compute the wind distribution from observations, both at the surface and aloft.

Approach C does not easily lend itself for use with Gaussian climatological models. Often, insufficient observations are available to drive a wind field model, and a mass-consistent, 3D modelling approach can be time consuming and costly.

An evaluation of the three approaches listed under method B has been recently undertaken by Lam et al (1984). They found that a stability-dependent power law approach was the overall best approach. In fact, this approach is the one used most frequently in the models evaluated. The stability-dependent power law approach is as follows:

$$u = u(R) \left(\frac{H_e}{R}\right)^P \qquad 3.2.1$$

where u is the wind speed, R the wind speed measurement height, H_e the effective plume height and P the stability-dependent exponent.

When using a Gaussian climatological model, the most practical approach to classifying stability is that of Pasquill-Gifford which allows the use of routine surface layer observations of wind speed, solar radiation, cloud cover, etc to be used to determine the stability. However, as more observations are added to the routine data collected, the possibility of classifying stability via more direct methods, such as σ_θ, σ_ϕ or heat flux, can be considered. Several schemes are available for determining P as a function of stability. Empirically-derived P exponents have been investigated by Kiely (1978) using Nanticoke data. The approach recommended by Lam et al (1984) is that proposed by Irwin (1979) which involves the use of surface measurements with surface layer similarity theory to derive the P exponents. Often, insufficient data are available at a site to determine the power law exponents as prescribed by Irwin. It is recommended that the site specific power law exponents of Kiely be used in the model for Lakeshore sites and those proposed by Irwin for flat sites be used elsewhere.

3.3 Vertical and Horizontal Dispersion

The predominant scheme for determining plume dispersion is the empirical method of Pasquill and Gifford (P-G), later modified and described by Turner in his workbook (1970). Curves for vertical and horizontal dispersion as a function of stability and downwind distance were derived from the Prairie Grass tracer experiments. The essential difficulty in applying the P-G curves universally is that the experiments were conducted over an open flat grassland, with surface level releases, and 3- to 10-minute averaging times. Plume dispersion is not only dependent on stability and downwind distance but also on surface roughness, release height, time-averaging period, and initial conditions.

Since Gaussian models are fairly sensitive to the σ_z input, some effort should be made to select the most representative dispersion parameterization for Ontario Hydro thermal station sites. Again, algorithms derived from Nanticoke measurements, Misra and McMillan (1979) are available. As well, schemes which modify the P-G curves for elevated releases, Pasquill (1983), extended averaging times Briggs (1978), and differences in roughness length, McElroy and Pooler (1968). Also available are schemes which utilize surface layer similarity theory to parameterize dispersion, Van Ulden (1978), Venkatram (1981).

The latter approach can be difficult to incorporate effectively in a Gaussian climatological model because available data generally limit the approach to stabilty classification.

Another important consideration, where vertical dispersion is concerned, is to limit vertical growth to the height of the boundary layer. Some data for mixing heights are available from studies conducted at the Lakeview, Misra (1982) and Nanticoke, Lui (1980) stations, respectively.

Since data are available for Hydro sites, it is recommended that these empirically-derived parameterizations for vertical dispersion coefficients be used in the model; otherwise the modified P-G curves for elevated releases will have to be used as summarized in Pasquill (1983).

To facilitate tabulation of the description of vertical dispersion in the models reviewed, the following categories were used:

A) Pasquill-Gifford

B) Modified Pasquill-Gifford

C) Similarity approach

D) Limited mixing

For the treatment of horizontal dispersion in climatological models, where σ_y covers the entire 360° of possible wind directions, a technique known as sector averaging is applied, whereby the frequency of occurrence of wind directions is determined for typically 16 sectors of the wind direction circle. For tabulation, the following were used:

A) Gaussian distribution

B) Sector averaging

where the 'Gaussian distribution' designates the approaches taken by the non-climatological models.

3.4 Removal Processes

In considering the long-term deposition of trace element emissions, the model must have modules which consider all of the important atmospheric removal processes; gravitational sedimentation, wet and dry deposition. Since Gaussian models do not explicitly treat the vertical transport process, it is difficult to modify these models for deposition in a way that is physically realistic.

Generally, two approaches for depletion are available for Gaussian models - surface-depletion or source-depletion, Horst (1984). The former approach is more complex in application, requiring more computer time, but is considered more realistic than the latter which is simpler in application but can lead to error when atmospheric conditions are extremely stable (ie: Pasquill F) or when deposition velocities are high. As it turns out, these conditions are usually rare, therefore the source-depletion approach is commonly used without introducing appreciable error. Horst (1984) proposes a profile correction to source-depletion terms as a means of overcoming error when such conditions are of concern. Similarly, the approach taken by Droppo (1982) to describe deposition in the CLIDE model, described in the following section, also eliminates error effectively under stable atmospheric conditions or high deposition velocities. However, the two correction approaches have not been compared, Droppo (1985). The corrected source-depletion approach used by Droppo is considered a superior approach for Ontario Hydro application as it also allows treatment of the influence of terrain on deposition patterns. The general form of the source-depletion removal process then is:

$$X(x) = Q_o \frac{Q(x)}{Q_o} F(x) \qquad 3.4.1$$

where (x) is downwind distance, X air concentration, Q_o is the source term, $Q(x)/Q_o$ is the deposition source-depletion term, and F(x) is the dispersion factor. The term Q(x) is then

$$Q(x) = D_D(x) + D_G(x) + W(x) \qquad 3.4.2$$

composed of the deposition amounts due to the dry deposition terms $D_D(x)$, gravitational sedimentation D_G, and the wet deposition term, W.

3.4.1 Dry Deposition

When the process of dry deposition by gravitational sedimentation and turbulent diffusion is considered, a deposition velocity (V_d) approach of some sort is taken, where

$$\text{Deposition} = V_d \cdot \chi \cdot \qquad 3.4.1.1$$

The deposition velocity is a complex function of atmospheric and surface conditions and pollutant properties. Reliable deposition velocity measurements for most trace elements are not available. Often, an all encompassing assumption of V_d = 1 cm/s for all chemicals is made for deposition calculations. However, an approach which reflects the variability of the deposition velocity for various chemical species, atmospehric and surface conditions is more desirable. The CLIDE model had the most physically realistic dry deposition algorithm, allowing dry removal to vary with wind speed, atmospheric stability, local ground cover and size distribution of the trace elements. For module review, the following distinctions were followed:

A) Gravitational sedimentation

B) Simple dry deposition

C) Complex dry deposition algorithm

3.4.2 Wet Deposition

As can be seen from equation 3.4.2, as long as a model has a removal process algorithm and a modular program structure, then wet deposition can usually be added without much difficulty. Wet deposition is an important removal mechanism and, therefore, should be part of the trace element deposition model selected.

Two approaches exist for determining wet deposition. A scavenging rate, where a precipitation scavenging coefficient is used to deplete the plume, analogous to a radioactive decay rate. Different parameterizations are required in this case for aerosols and gases. The scavenging rate is a function of particle size, rain intensity, mass-mean drop radius, pollutant characteristics, time and position (ie, height). For many reasons, very crude approximation to wet deposition (ie: order of magnitude), Slinn (1978), are usually made via this approach. For example, empirical data on collection efficiencies of submicron particles vary over 3 orders of magnitude; detailed information on precipitation (type, rate, drop size, snow flake morphology) is not usually available; influence of particle growth by water vapour condensation can be significant; etc.

The second approach to characterizing wet deposition is analogous to the dry deposition parameterization, that is, a wet deposition velocity V_w is defined via a washout ratio W_r, which is the ratio of the pollutant concentration in surface-level precipitation to the concentration in surface-level air. This approach is more accurate (ie: factor of 2) for long-term average calculations, Slinn (1978). The wet deposition is, therefore, determined by

$$D_W = V_w \chi = W_r P_o \qquad 3.4.2.1$$

where P_o is - for climatological modelling - a long-term average precipitation rate (ie: cm/a). Tables of washout ratios are available in the literature, Sehmel (1984). For purposes of tabulating module attributes two wet deposition approaches were defined:

D) Precipitation scavenging

E) Wet deposition velocity

3.5 Terrain Effects

Some form of complex or non-flat terrain treatment is necessary for the Ontario Hydro trace element model as all of our power station sites are located in complex terrain. The most common approach of taking into account non-flat terrain in Gaussian models is a simple kinematic approach where the plume centre line height is adjusted by the amount of height difference between the source and the receptor. Problems can occur with this approach if the plume centreline adjustment intersects the terrain. Therefore, a minimum distance between the effective source height and the terrain is imposed.

Another approach, taken by Droppo in the CLIDE model, is facilitated through the dry deposition parameterization which allows the input of surface roughness elements which can vary over the modelling region. This approach is the more realistic of the two methods. For tabulation, the following were used:

A) Kinematic

B) Surface roughness

3.6 Summary of Module Review

Table III summarizes the review of the key modules discussed here. This information was derived from a review of the models descriptive information and from a review of models by Liu (1982). This table provides a basis for selecting a model and specifying model enhancements.

An important aspect of model optimization or module improvement is the trade off between time and cost required for an improvement versus the gain in model performance. In order to assist in this decision-making procedure, the results of a study of key module sensitivity in Gaussian models, Liu (1982), is repeated here in Table IV.

TABLE IV

SUMMARY OF SENSITIVITY OF GAUSSIAN MODELS TO VARIATION IN KEY ALGORITHMS

Algorithm	Sensitivity
Plume rise	factor of 3
Exponent in power law wind profile	20 per cent
Horizontal dispersion coefficient	factor of 2
Vertical dispersion coefficient	order of magnitude

It is clear from Liu's study that efforts aimed at improving model vertical dispersion and plume rise treatments should yield the most return in model prediction improvement.

It is apparent from Table III that current modules for plume rise are available from several of the models reviewed. Additionally, as discussed earlier, a site-tuned plume rise model is available for Nanticoke and lakeshore power plant sites similar to Nanticoke.

Several up-to-date modules for vertical dispersion are also available from the group of models reviewed; for example, RAM, CDM, ISCLT, CLIDE all offer modified versions. However, none of the models use the more desirable similarity approach. But, until the routine data available offer some of the information needed in similarity approaches, there is no advantage to adopting a similarity module at this time. For other key modules, the table indicates there are several models from which up-to-date modules can be selected for inclusion in the base model.

4.0 SELECTION OF BASE MODEL

The two candidate base models for trace element deposition are CLIDE and ISCLT. The purpose of this section is to table the rationale for selecting one over the other, not to provide

TABLE

Model Review Summary

TECHNICAL CHARACTERISTIC / MODEL	CLIDE	ISC ISCLT	VALLEY	AQSTM	ATM	TEM	TCM	MULTI MAX	CDM CDMQC	MPTER	PAL	PT DIS	PT MAX	PT MTP	SCIM	MESO PUFF	RAM	CRSTER	MSDM	GEM
PLUME RISE																				
a) Briggs 1969	X				X	X	X		X						X	X				X
b) Briggs Post 69		X	X	X				X		X	X	X	X	X			X	X		
c) Non Briggs																			X	
VERTICAL WIND SHEAR																				
a) Constant	X		X		X							X	X	X		X				
b) Extrapolation		X		X		X	X	X	X	X	X				X		X	X	X	
c) Wind Field																				X
VERTICAL DISPERSION																				
a) Pasquill			X	X	X	X	X	X		X		X	X	X		X		X		X
b) Modified Pasquill	X	X							X		X				X		X		X	
c) Similarity																				
d) Limited Mixing	X	X	X					X		X	X	X		X		X	X	X	X	X
HORIZONTAL DISPERSION																				
a) Gaussion distribution				X		X		X		X	X	X	X	X	X	X	X	X		X
b) Sector Averaging	X	X	X		X		X		X										X	
REMOVAL PROCESSES																				
a) Gravitational Sedimentation	X	X																		
b) Simple Dry Deposition		X		X						X										
c) Complex Dry Deposition	X																			
d) Scavenging Rate	X																			
e) Washout Ratio																				
TERRAIN DEFECTS																				
a) Kinematic		X	X	X				X		X					X			X		X
b) Surface Roughness	X																			

detailed descriptive information on these models. This information is available, in the case of the CLIDE model, from Droppo (1982), Vaughan (1984) and, in the case of the ISCLT model, from the 800 pages of user's manuals, Bower et al (1979).

The CLIDE model was originally developed by Battelle Pacific Northwest Laboratory as a long-term climatological model, ANDEP (annual deposition), incorporating wet and dry deposition, for modelling long-term local, terrestrial and aquatic deposition from an electric power plant. It has been revised since its inception to incorporate state-of-the-art modules for plume depletion, Droppo et al (1982), and to specifically model trace element emissions from coal-fired facilities, as part of the CEA-funded trace element deposition project, Van Voris et al (1983), Droppo (1985).

The CLIDE model is of modular design thus facilitating the replacement of old algorithms and the addition of new modules when required. The model currently incorporates all of the necessary parameterizations for addressing the trace element deposition problem. The model is particularly outstanding in its approach to dry removal. The model is somewhat flexible for other applications that require a Gaussian climatological modelling approach.

The ISCLT model was developed by H.E. Cramer Co Inc of the USA, under contract by the US EPA, for use in general regulatory applications there. It was specifically designed to meet the need for complicated dispersion analyses. It is thus a flexible model containing options to meet a variety of complex dispersion scenarios. Model options include site-specific wind profile exponents, vertical potential temperature gradients, source-specific plume entrainment coefficients, building wake effects, dry deposition, etc.

The ISLT model is recommended by Cramer et al as suitable for the following applications:

- stack design studies
- combustion source permit applications
- regulatory variance evaluation
- monitoring network design
- control strategy evaluation
- fuel conversion studies
- control technology evaluation
- new source review
- prevention of significant deterioration.

The model is also not specifically recommended for long-term deposition studies. The primary reason for this is that it does not treat wet deposition - an important aspect. The model structure does not allow easy inclusion of wet deposition. Also, because the model architecture has to meet a vast range of scenarios, some processes are treated simply, such as the treatment of complex terrain. It would be impossible to rewrite the dry deposition module to account for the influence of surface roughness and variations in deposition velocity, as is done in the CLIDE model, without restructuring the entire ICSLT program code.

As part of this phase of the project, the fortran computer codes for both the CLIDE and ISCLT models were obtained.

The CLIDE model is considered more desirable as a base model for trace element deposition modelling for the following reasons:

- it is specifically designed for evaluation of trace element emissions from coal-fired power plants;
- it has credibility and is defendable from the technical point of view (eg, the CEA/Battelle trace element deposition studies);
- its design is flexible enough to accommodate algorithm replacements and additions;
- it contains a state-of-the-science treatment of removal processes, in particular dry deposition parameterization;
- it requires less modification for implementation than would the ISCLT model;
- it is versatile enough to accommodate other applications which may require a Gaussian climatological approach.

5.0 CONCLUSIONS AND RECOMMENDATIONS

A review of a group of available Gaussian models has been successfully undertaken and a base model which is credible and defendable on technical merit has been selected for use in determining the deposition of trace elements around Ontario Hydro fossil-fired generating stations.

The selected model, 'CLIDE' with recommended improvements, will represent an up-to-date approach to trace element deposition modelling. Specific recommendations for improving CLIDE include:

- the addition of site-specific plume rise algorithms where possible (ie: Nanticoke), otherwise the upgrading of the current pre-1969 Briggs plume rise to post-1969 Briggs;
- the addition of site-specific power law profile exponents, where available, to the wind shear algorithms;

- improvement of the wet deposition algorithm to a washout ratio approach, from the current scavenging rate approach;
- addition of site-specific vertical dispersion coefficient algorithms, where available (ie: Nanticoke).

5.1 Scope of the Recommended Model Development

The following table is a listing of the tasks recommended for the Phase IV model implementation project.

TABLE V

TASK SUMMARY OF PHASE IV

Task	Description
1) Review of model code and selection of suitable computer for implementation	A fortran code for the CLIDE program has been made available to Ontario Hydro. The program is designed for use on a VAX 780 computer. However, it may be suitable for installation on an IBM PC compatible system. This task will involve scrutiny of the code and selection of appropriate in-house computing facility.
2) Base model implementation	Once the computer system has been selected, the base model will be installed onto that system. This may involve rewriting parts of the code to accommodate fortran incompatabilities and changes to the program.
3) Module upgrade	This will involve implementing the proposed module upgrades to the base model, including addition of options for various modules for site-specific algorithms where appropriate. At this stage of the modelling program it is proposed to invite the author of the CLIDE model Dr. Jim Droppo of Battelle Pacific Laboratory to visit Ontario Hydro Research for consultation on the model development.

4) Development of site characteristics data base	Each of our thermal power plant sites of interest (ie: Nanticoke, Lakeview, Atikokan, Lambton, and Thunder Bay) have different site characteristics. The model allows the input of site-specific terrain parameters. These will have to be abstracted from topographical maps and stored in the computer.
5) Development of meteorological data base	Appropriate climatological input meteorological data required by the model for each site will have to be assembled and input into the computer. One year of data is considered a minimum for a site with 6 to 10 years of data more desirable. M&E costs will be incurred in obtaining these data.
6) Development of source data base	This task will involve taking emissions characteristics data provided by EPD of CTS, and inputing them into the computer. Data required will be pollutant species of interest, particle size distribution, concentration, emission rate.
7) Testing of modelling capability	With the model implemented and the required data bases established, test the model.
8) Prepare final report describing the modelling capability	A final report describing the developed modelling capability will be prepared.

It is envisioned at this time that a fifth phase of the trace element program will involve establishing model credibility and passing on the developed trace element deposition modelling capability to EPD.

5.2 Proposed Timetable

Table VI summarizes the proposed schedule for Phase IV.

5.3 Budget Proposal

Table VII summarizes the cost associated with Phase IV as proposed.

TABLE VI

PROPOSED SCHEDULE

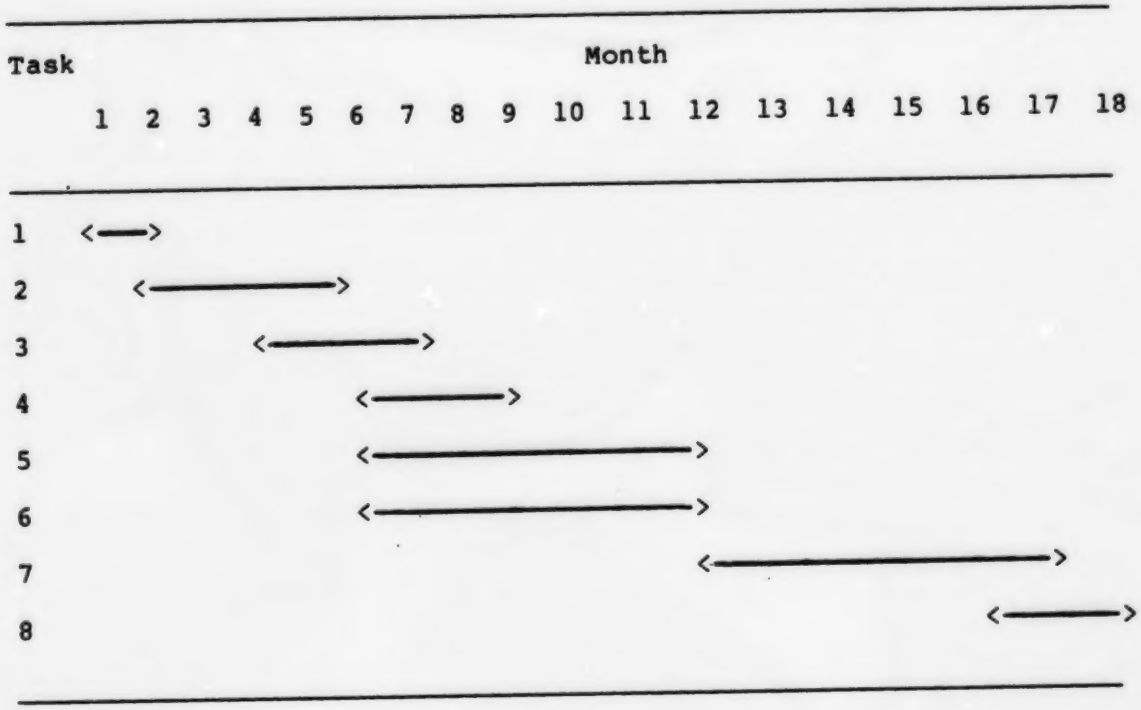

TABLE VII

Task	Labour					Expense				
	Man-days				Total ($)	Travel	Material	Services Outside Research Division	Total	Total Labour and Expense
	Computer Scientist	Atmospheric Physicist	Computer Programmer	Technician						
1	15	2			7,000					7,000
2	10		8		8,200					8,200
3	15	5	5		7,500	2,000		1,500	3,500	11,000
4			3	12	4,000					4,000
5	2	2	5	5	4,400		2,500			6,900
6			5	2	2,000					2,000
7	10	5	2		6,700					6,700
8	15	5	2	2	9,400					9,400
Grand Total	67	19	30	21	49,200	2,000	2,500	1,500	3,500	55,200

It is estimated that material and expense costs for collecting the climatological data required will be $2,500. Also proposed, if deemed necessary at some point during model development, the model's author, Dr. Jim Droppo of Battelle Pacific Laboratory will be retained for consultation. This may involve his visiting Hydro. A cost of $3,500 is estimated, if this option is elected.

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